

Seasonal Behavior of Particulate
Matter at Three Rural Utah Sites

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SEASONAL BEHAVIOR OF PARTICULATE MATTER AT THREE RURAL UTAH SITES

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Abstract—Elemental analysis of size-segregated particulate samples for three rural Utah sites is presented and discussed. Daily samples were collected at each site in three size ranges (15–3.5 μm , 3.5–0.5 μm , and 0.5–0.1 μm) for a period of one year.

Sulfur is shown to be important in the two smaller size ranges. There is no distinctive seasonal pattern in sulfur concentrations.

Overall, the mass contribution of the soil related components to ambient particles is greatest. Soil related elements dominate in the two larger size ranges and are significant (amounting to about 50%) in the smallest size range. The soils show a distinctive seasonal variation with winter concentrations, about a factor of three smaller during the summer. Small particle soils may be a significant cause of visibility degradation.

INTRODUCTION

The western region of the United States has been proposed for electric power generating facilities, oil shale development, and coal conversion facilities (Pitchford *et al.*, 1978). The impact on the environment must be documented, and this can be achieved by establishing baseline values and evaluating any changes due to subsequent developments. This paper discusses a project funded by the United States Environmental Protection Agency to establish baseline particulate levels at Canyonlands, Zion, and Henrieville, Utah. The particulate samples were collected in three size ranges by means of Sierra Instruments Multiday Impactors and analyzed by particle induced X-ray emission. Quarterly averages for the major elements which allow comparisons of periods during snow cover with dry summer conditions, are presented as well as a discussion of possible sources.

SITES

Samples were collected at three locations in Utah: Zion National Park, Canyonlands National Park, and Henrieville (see Fig. 1).

The sampler at Zion was situated near the center of a wide spot (800 m) in a canyon approximately 1 km from the park's south entrance. The sampler intake is about two meters above the ground at an altitude of 1200 m mean sea level (MSL). The canyon floor in the vicinity of the sampler has good ground cover of grass, shrubs, and a few trees. The principal highway

through the park (averaging about 2000 cars per day) spans the bottom of the canyon about 120 m west of the sampler. All roads in the vicinity of the sampler are paved. A park camping area is approximately 800 m to the south. Predominant winds are up the canyon (north-northeast) during the day and down the canyon (south-southwest) at night.

A second sampler was on top of a 5 m tower located about 10 km east of Bryce Canyon National Park and 3 km west of Henrieville, Utah. The tower is on a small plot of irrigated farmland (1800 m MSL) surrounded by low mesas. The roads in the vicinity of sampler are unpaved. A single family residence lies approximately 70 m north of the site. Upslope winds are predominately to the east and downslope to the west.

The third sampler is on a high plateau (1800 m MSL) overlooking the Colorado River Canyon near the Island in the Sky Ranger Station in Canyonlands National Park, Utah. The sampler intake is protruding through the roof of a small trailer placing it about 4 m above the ground. Ground cover is sparse, primarily small trees and shrubs. The access road (to Island in the Sky) is paved with a crushed rock and is 400 m east of the site. Northeast of the sampler 100 m, near the top of a hill (20 m above the sampler location), is a diesel-electric power supply for the ranger station.

SAMPLE COLLECTION

The instrument used to collect particulate matter at the sites was a Multiday Impactor.* This device, which

*Sierra Instruments Corp., Carmel, California.

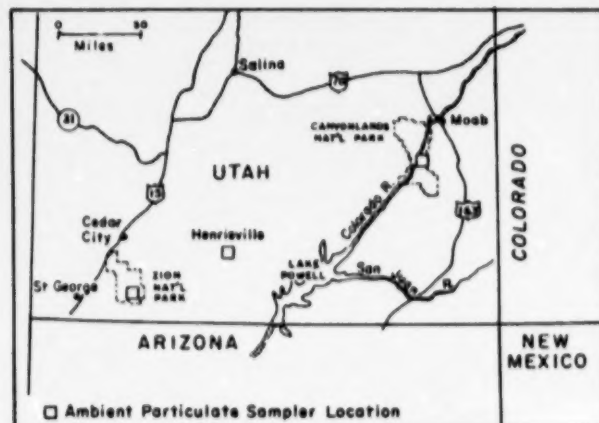


Fig. 1. Map of three Utah sites.

is a rotating drum impactor of the Lundgren type, is described elsewhere (Flocchini *et al.*, 1976). This instrument is capable of automatically taking seven 24 h duration samples, and provides enough information on particle size to allow identification of particles capable both of long range transport and efficient degradation of visibility (Barone *et al.*, 1978). The intake represents a particle cut at $15\text{ }\mu\text{m}$ at low wind velocities, while the first cut point lies at $3.5\text{ }\mu\text{m}$ and the second at $0.5\text{ }\mu\text{m}$. Collection surfaces on the rotating drums were $600\text{ }\mu\text{g cm}^{-2}$ mylar type S coated with $65\text{ }\mu\text{g cm}^{-2}$ Apiezon Type L grease. The filter was a $0.4\text{ }\mu\text{m}$ pore size Nuclepore. The unit has been evaluated in numerous tests, the most recent at the Environmental Protection Agency-Department of Energy comparison at Charleston, West Virginia (Camp *et al.*, 1978). The unit delivers samples suitable for optical, β -gauge, and X-ray analysis in three size ranges: $15-3.5\text{ }\mu\text{m}$ (Stage 1), $3.5-0.5\text{ }\mu\text{m}$ (Stage 2), and $0.5-0.1\text{ }\mu\text{m}$ (Stage 3).

Sampling began in August, 1977, at Henrieville and Canyonlands. Sampling continued at Henrieville until January, 1979, and the unit at Canyonlands is still operating. Sampling began at Zion in October, 1977, and to this day particulates are still being collected.

SAMPLE ANALYSIS

All samples were analyzed by particle induced X-ray emission (PIXE) for elements sodium and heavier. A discussion of the sensitivity and accuracy of this system is found elsewhere (Cahill *et al.*, 1976). An 18 MeV alpha beam from the 76 in. isochronous cyclotron, located at the University of California, Davis, excites X-rays in the particulate sample. The characteristic X-ray corresponding to a transition of any element, sodium and heavier, are converted to a digital signal processed by a PDP 15/40 computer. By evaluating the energy and total number of these X-rays, the element is

identified and a concentration is computed (Harrison and Eldred, 1973). The analytical system has been evaluated by various interlaboratory comparisons achieving mean absolute accuracy of $\pm 6\%$ for aluminium and heavier elements (Camp *et al.*, 1975, 1978).

RESULTS

The data presented in Table 1 is a quarterly summary of the major elements. This was prepared by first summing the three stages and then averaging all the data available within the quarter. Nominal errors are $\pm 15\%$. The standard deviations associated with these means typically range from the mean to half the value of the mean. For comparison, data gathered (Flocchini *et al.*, 1978) at five urban Californian sites are included.

Table 2 is a summary of the soil type elements Lawson and Winchester, 1978) in the $15-3.5\text{ }\mu\text{m}$ size range. The average amount of silicon, the ratio of a specific element to silicon, and bivariate correlation coefficients (Cahill *et al.*, 1977) between silicon and the element of interest are presented.

Figure 2 is a presentation of the major elements in the $15-3.5\text{ }\mu\text{m}$ size range for Zion National Park. These data are monthly averages for the period January, 1978-December, 1978.

Figure 3 is a presentation of the major elements in the $3.5-0.5\text{ }\mu\text{m}$ size range, and Fig. 4 represents the $0.5-0.1\text{ }\mu\text{m}$ size range.

DISCUSSION

An examination of the elemental data (Table 1) demonstrates a decrease of the soil component, in the winter months. This occurs at all sites during the first quarter of 1978 as well as the last quarter of the same year. Further data reveals that the first quarter of 1979 follows the same trend. This can be attributed to snow cover curtailing any wind blown dust.

Table 1. Particulate concentration (ng m^{-3}) of major elements in the 15–0.1 μm size range

	Month	Si	K	Ca	Fe	Cl	S	Pb	Zn	Cu
1977										
Henrieville	7, 8, 9	1753	175	668	205	30	725	79	25	19
Canyonlands	7, 8, 9	1704	401	449	213	351	498	94	23	34
Henrieville	10, 11, 12	1595	153	561	176	575	521	185	3	12
Canyonlands	10, 11, 12	1230	414	340	175	453	665	30	11	98
Zion	10, 11, 12	684	49	197	98	48	387	51	7	14
1978										
Henrieville	1, 2, 3	494	70	201	91	64	356	40	18	10
Canyonlands	1, 2, 3	708	207	242	127	176	477	4	21	13
Zion	1, 2, 3	559	83	180	118	75	303	48	15	15
Henrieville	4, 5, 6	1680	217	609	254	96	378	19	13	16
Canyonlands	4, 5, 6	1866	276	526	282	111	424	31	12	216
Zion	4, 5, 6	1813	218	558	309	80	403	41	15	16
Henrieville	7, 8, 9	1376	186	557	186	40	577	37	26	9
Canyonlands	7, 8, 9	984	129	239	135	43	418	10	11	40
Zion	7, 8, 9	1187	148	331	183	68	501	54	18	22
Canyonlands	10, 11, 12	541	136	135	92	70	175	11	3	13
Zion	10, 11, 12	450	81	179	69	43	328	48	11	8
1973										
Oakland	7, 8, 9	1339	313	528	764	2014	1258	904	30	26
Sacramento	7, 8, 9	3372	591	527	1215	336	1016	704	132	8
Bakersfield	7, 8, 9	4566	1743	1252	1819	18	1507	1072	47	14
Los Angeles	7, 8, 9	2418	473	1063	1006	123	4013	1498	183	20
San Diego	7, 8, 9	3680	560	772	1327	296	2663	1041	39	7

It was felt that since the sites were essentially dominated by the soil constituents, a further examination was necessary. Table 2 presents both the ratios and correlations of the soil components in the 15–3.5 μm size range.

Aluminum exhibits a strong correlation (> 0.70) with silicon in most cases. Exceptions include Canyonlands during the third quarter of 1977 and Zion during the last quarter of 1978. The ratio is similar at each site within a given quarter. There appears to be a seasonal variation in this ratio, unlike

what has been reported for urban sites (Barone *et al.*, 1978). In most cases, the ratio is higher than the crustal average indicating an aluminum rich soil for this area. Table 3 presents the crustal average (Chemical Rubber Publishing Co., 1959) as well as the average ratio found at the sites studied.

Calcium also exhibits a strong correlation with silicon. All sites are considerably enhanced with respect to the crustal average. Henrieville is slightly more calcium rich than both Zion and Canyonlands.

The iron-silicon correlation is the most stable of

Table 2. Ratios and correlations (ratio/correlation) of major soil components to silicon in the 15–3.5 μm size range

	Month	Si(ng m^{-3})	Al/Si	K/Si	Ca/Si	Ti/Si	Fe/Si
1977							
Henrieville	7, 8, 9	1307	0.38/0.81	0.11/0.79	0.39/0.81	0.03/0.72	0.12/0.79
Canyonlands	7, 8, 9	1160	0.38/0.76	0.24/0.31	0.28/0.93	0.02/0.93	0.14/0.98
Henrieville	10, 11, 12	976	0.49/0.69	0.13/0.66	0.46/0.93	0.01/0.41	0.11/0.98
Canyonlands	10, 11, 12	790	0.33/0.53	0.32/0.19	0.32/0.83	0.01/0.90	0.15/0.97
Zion	10, 11, 12	490	0.31/0.84	0.10/0.91	0.31/0.95	0.01/0.86	0.14/0.98
1978							
Henrieville	1, 2, 3	294	0.55/0.87	0.14/0.92	0.44/0.93	0.64/0.07	0.18/0.89
Canyonlands	1, 2, 3	506	0.49/0.90	0.29/0.80	0.42/0.96	0.03/0.66	0.17/0.96
Zion	1, 2, 3	362	0.50/0.86	0.18/0.81	0.40/0.88	0.02/0.37	0.20/0.89
Henrieville	4, 5, 6	1032	0.36/0.52	0.11/0.76	0.39/0.79	0.01/0.64	0.14/0.79
Canyonlands	4, 5, 6	1402	0.26/0.94	0.24/0.75	0.33/0.97	0.01/0.94	0.12/0.98
Zion	4, 5, 6	1081	0.34/0.67	0.11/0.85	0.32/0.91	0.01/0.77	0.16/0.87
Henrieville	7, 8, 9	805	0.45/0.85	0.13/0.93	0.43/0.96	0.01/0.88	0.14/0.97
Canyonlands	7, 8, 9	552	0.49/0.78	0.12/0.96	0.26/0.98	0.02/0.90	0.14/0.98
Zion	7, 8, 9	730	0.44/0.77	0.12/0.97	0.30/0.95	0.02/0.89	0.16/0.96
Canyonlands	10, 11, 12	396	—	0.29/0.71	0.29/0.98	0.14/0.07	0.25/0.94
Zion	10, 11, 12	298	0.46/0.66	0.31/0.87	0.33/0.76	0.05/0.68	0.14/0.90

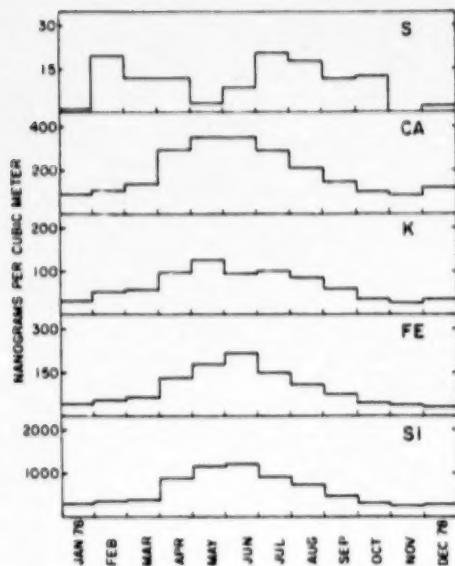


Fig. 2. Elemental concentrations in the 15-3.5 μm size range at Zion during 1978.

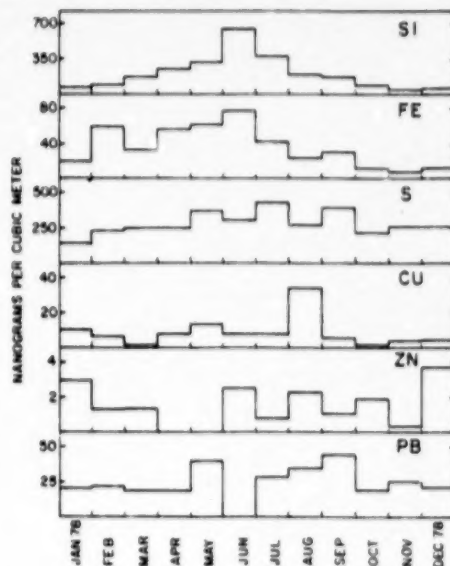


Fig. 4. Elemental concentrations in the 0.5-0.10 μm size range at Zion during 1978.

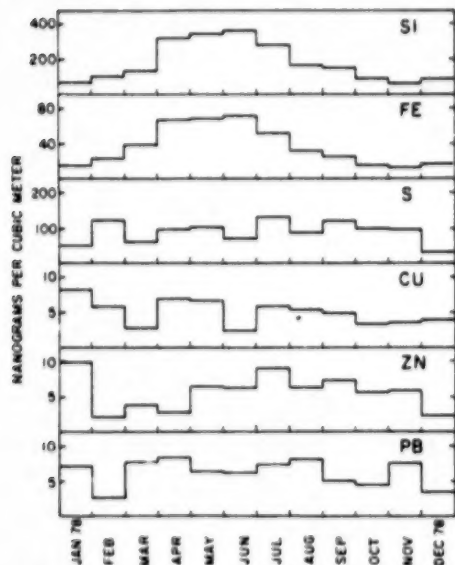


Fig. 3. Elemental concentrations in the 3.5-0.5 μm size range at Zion during 1978.

those examined. The correlation remains higher throughout the sampling period. The ratio at Canyonlands and Zion remains constant through a majority of the sampling period with a slight elevation during the fourth quarter of 1978.

Table 3. Crustal concentrations of major elements and ambient levels at Henrieville, Zion, and Canyonlands. All levels normalized to silicon

	Crustal Average	Henrieville	Zion	Canyonlands
Al	0.293	0.40	0.37	0.56
Si	1.000	1.00	1.00	1.00
K	0.093	0.12	0.12	0.25
Ca	0.131	0.42	0.33	0.31
Ti	0.016	0.02	0.02	0.04
Fe	0.180	0.21	0.18	0.15

Titanium-silicon correlation coefficients are typically high; the exception occurs in the winter months. The ratio of titanium to silicon found is very close to the crustal average.

If Canyonlands were ignored, the potassium-silicon correlation and ratios would be characterized as very stable. The ratio at Henrieville and Zion is slightly elevated above the crustal average but constant throughout the period presented. Canyonlands exhibits a very elevated ratio during the period August, 1977, to June, 1978. During this period, the correlation to silicon ranges from very poor (0.19) to acceptable (0.75).

This uncharacteristic behavior led the authors to examine this further. Potassium has been suggested as a tracer for agricultural burning (Lyons *et al.*, 1979). This possibility was examined and found to be negative. The correlations of other elements to potassium were examined. It was found that chlorine and potassium correlated very strongly (greater than 0.89)

during the period of August, 1977 to March, 1978. During the second quarter of 1978 the correlation dropped to 0.46 at a time, when the silicon-potassium correlation increased. The third quarter shows potassium-silicon correlation increasing to 0.96, while the chlorine-potassium drops again to 0.16.

These data suggested a dual source for potassium. The area was examined for a second source that would supplement the soil. Located at Moab, Utah is a muriate facility with an estimated capacity of $1.8 \times 10^8 \text{ kg a}^{-1}$ (Bureau of Mines, 1975). This is an underground solution mine that employs solar evaporation. An examination of the amount of potassium from this facility would require a study of the local meteorology.

An examination of the Zion data as a function of size is presented in Figs. 2, 3, and 4 which are plots of

monthly mean concentrations of selected elements. The standard errors of the mean (Kennedy and Neville, 1976) for the values presented are typically 10–20% of the mean. Figure 2 includes the soil components as a representation of particles in the coarse mode. The data presented are a monthly average of 24 h values for Zion. It is seen that the soil constituents follow the same pattern as would be expected of a correlated set. Figure 3 presents the data in the $3.5 - 0.5 \mu\text{m}$ range. If iron and silicon are taken to be indications of the soil components we see that soil particles in this stage behave similarly to the coarse mode. Figure 4 which presents data in the $0.5 - 0.1 \mu\text{m}$ size range indicates a slightly different pattern for fine silicon and a possible secondary source of iron. The source of the fine silicon is the subject of another paper.

Returning to Table 1 it can be seen that sulfur is

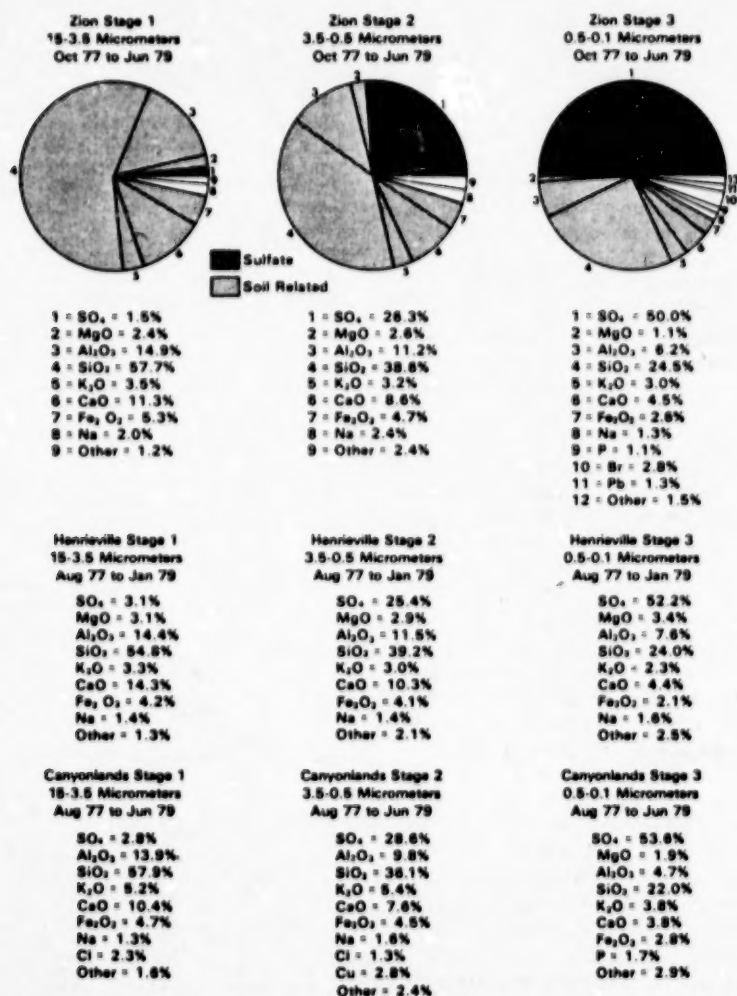


Fig. 5. Pie-graphs of size-fractionated mass balance for Zion, Utah, October 1977–June 1979, with corresponding table of percent composition. Similar tables for Henrieville and Canyonlands. Mass was determined by combining measured elemental and assumed oxide masses.

detected at all sites. At no site is there an increased impact of elemental sulfur. Sulfur in the intermediate size range is fairly flat throughout the year (Fig. 3) whereas there appears to be a slight peak in the fine mode (Fig. 4).

Lead, which is predominantly in the small size range (Fig. 4), appears consistent with vehicular traffic in both concentration and seasonal variation. The existence of other lead sources would have to be evaluated with meteorological data.

The high levels of copper (relative to the two other sites) at Canyonlands during the last quarter of 1977, as well as the second quarter of 1978, indicate the possibility of impact by transport. An analysis of transport would require an examination of source locations and emission factors, as well as meteorological parameters. The material is presented here to illustrate that even the use of quarterly averages can result in the detection of exceptional cases. However, closer examination of the 24-h data reveals that a few days dominate the quarterly average. 14, 15, 16, and 17 May are examples of highly impacted times with concentrations about two orders of magnitude higher than the typical data in that season. These data are responsible for an increased quarterly average. The remainder of the days are more indicative of the levels that occur at the site. It should be noted that approximately 60% of the copper occurs in the 0.5–0.1 μm size range, 37% in the 3.5–0.5 μm size range with the remainder in the coarse mode.

Data from five urban Californian sites are presented in Table 1 for comparative purposes. Behaviors of particulate concentrations at the three park sites were similar showing less variation than the urban Californian sites. Automotive influence at the park sites, even during periods of heaviest tourism in summer, was minor, as shown by mean lead values that averaged around 5% of Californian urban values. Copper, on the other hand, was higher at park sites than for most Californian cities, while soils (Al, Si, K, Ca, Fe) averaged about 60% of urban values. Sulfur averaged about 0.5 g m^{-3} (equivalent to 1.5 g m^{-3} , if present as sulfate), 15–50% of Californian values.

The size-fractionated measured elemental mass with assumed oxide levels on the three sites are presented in Fig. 5. It is assumed that the sulfur is in the form of sulfate and the soil related elements have typical oxide levels (Chemical Rubber Publishing Co., 1959). This analysis suggest an overwhelming influence of soil related materials in the 15–3.5 μm range. Sulfur in the form of sulfates is somewhat important in the 3.5–0.5 μm size range and accounts for about 50% of the 0.5–0.1 μm size range. It is interesting to note that the elements typically associated with soils maintain a substantial influence even in these two smaller size ranges. Small particle soil related elements may have as significant an impact on visibility degradation as sulfates.

SUMMARY

Examination of the particulate data for Canyonlands, Zion, and Henrieville has led to the following conclusions:

- (1) The area is largely impacted by soil components.
- (2) The amount of sulfur is fairly constant and approximately the same at all sites.
- (3) An additional source of coarse potassium exists at Canyonlands. There is also a large, processing plant approximately 12 km away.

The data presented will be evaluated with the meteorological parameters that were measured by different organizations during the sampling period. This will be the subject of another publication.

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